Engine Control Research under NASA Aviation Safety Program Overview

OA Guo

Controls and Dynamics Branch

December 11-12, 2013

Enhanced Engine Control Session

Presentations:

10:20AM	Overview (OA Guo)
10:30AM	C-MAPSS40k V2.0 Overview and Update (Jeff Chapman)
10:50AM	Controller Design for Enhanced Engine Response (James Liu)
11:15AM	Using Propulsion System for Loss of Control Prevention and Mitigation (Jonathan Litt)
11:40AM	Engine Icing Modeling, Detection and Accommodation (Ryan May)

Posters:

- C-MAPSS40k
- T-MATS (Toolbox for the Modeling and Analysis of Thermodynamic Systems)
- Integrated Flight and Propulsion Control

VSST Enhanced Engine Control Team members

Government:

- NASA Glenn Research Center
- NASA Langley Research Center

Onsite contractors:

- N&R Engineering
- Vantage Partners, LLC

Industrial partners:

- Pratt & Whitney
- Boeing

Enhanced Engine Research Overview

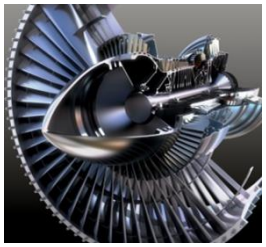
- Aviation Safety Program
  - Vehicle Systems Safety Technologies Project (VSST)
    - Assure Safe & Effective Aircraft Control (ASC)

      Loss of Control (LOC) Theme Problem under VSST
- Simulation Tool Development
  - C-MAPSS40k V2.0
  - T-MATS (Toolbox for the Modeling and Analysis of Thermodynamic Systems)
- Enhanced Engine Control Research for LOC
  - Risk based engine control
  - Loss of control prevention and mitigation
  - Integrated Flight and Propulsion Control
- Control Element for Engine Icing
  - Engine Icing modeling, detection and accommodation

Vehicle Systems Safety Technologies Overview

Improve Vehicle Safety by Proactively Mitigating Current and Future Risks

Improve Crew Decision-Making and Response in Complex Situations



Maintain Vehicle Safety between Major Inspections

Assure Safe and Effective Aircraft Control under Hazardous Conditions

Reduce current risks; Identify and proactively mitigate new risks

Assure Safe and Effective Aircraft Control under Hazardous Conditions (ASC)

Today

Aircraft Dynamics and Control Limitations under Hazardous Conditions can lead to Loss of Control (LOC)

- Current crew training under LOC conditions is limited due to model limitations for full stall conditions, failures and damage, and environmental hazards
- Information currently provided to the crew does not clearly inform of impending LOC
- Current autopilot systems are designed for nominal operations and often disengage under off-nominal conditions
- Current envelope protection systems provide limited capabilities

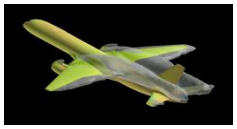
Tomorrow

Potential Increase in LOC Accidents Resulting from

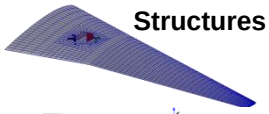
- Increasing demand on the National airspace requiring high-density operations
- Increased demand on crew & automated systems
- Increased external hazard encounters (wakes, weather)
- New materials and vehicle configurations

Enhanced Vehicle Simulation under Hazardous Conditions

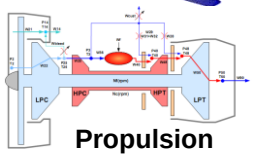
Aerodynamics



Structures

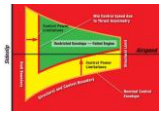


Propulsion

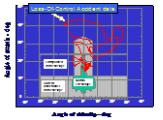


Safe & Effective Vehicle Control under Multiple LOC Hazards

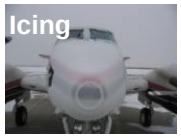
LOC Risk Prediction & Dynamic Envelope Estimation



Upset Prevention & Recovery



Multiple Hazards Mitigation



LOC Working Group to Identify Emergent Risks, Define Test Scenarios, & Develop Evaluation Requirements

Enhanced Engine Research Activities

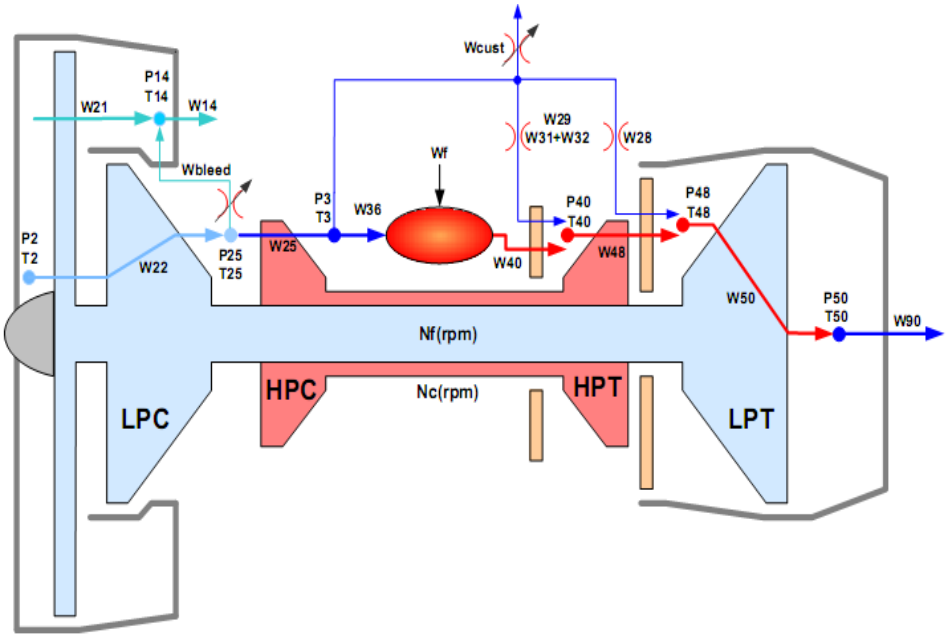
- In-House Research:
  - Faster Response Engine Research
  - Off-Nominal Operation Modeling and Control
    - ✓ Off-schedule VSV, VBV operation
    - ✓ High inlet angle operation simulation
    - ✓ **Risk based engine control**
    - ✓ **Envelope protection using propulsion systems**
    - ✓ **Engine icing accretion simulation, detection, and control**
  - A New Open Source Thermodynamic System Simulation Tool
    - ✓ Simple simulation tool for propulsion systems
    - ✓ Openly available to everyone
- Integrated Flight and Propulsion Research:
  - "Piloted Flight Simulator Evaluation of Faster Engine Responses" – Boeing, (August 2010 – June 2011)
  - "Integrated Flight and Propulsion Control Architecture Study" – Pratt & Whitney (Sept. 2011 – March 2013)
  - Joint effort among NASA Glenn Research Center, NASA Langley Research Center, Pratt & Whitney, and Boeing

Simulation tool development

- C-MAPSS40k
  - Continue improving
  - New stall margin calculation
  - Generating linear models
  - Expanded flight envelope
  - and many more
- T-MATS (Toolbox for the Modeling and Analysis of Thermodynamic Systems)
  - General thermodynamic simulation tool
  - Variable input system solvers
  - Advanced turbo-machinery block sets
  - Control system block sets
  - **Open source software**

Commercial Modular Aero Propulsion System Simulation 40,000 (C-MAPSS40k)

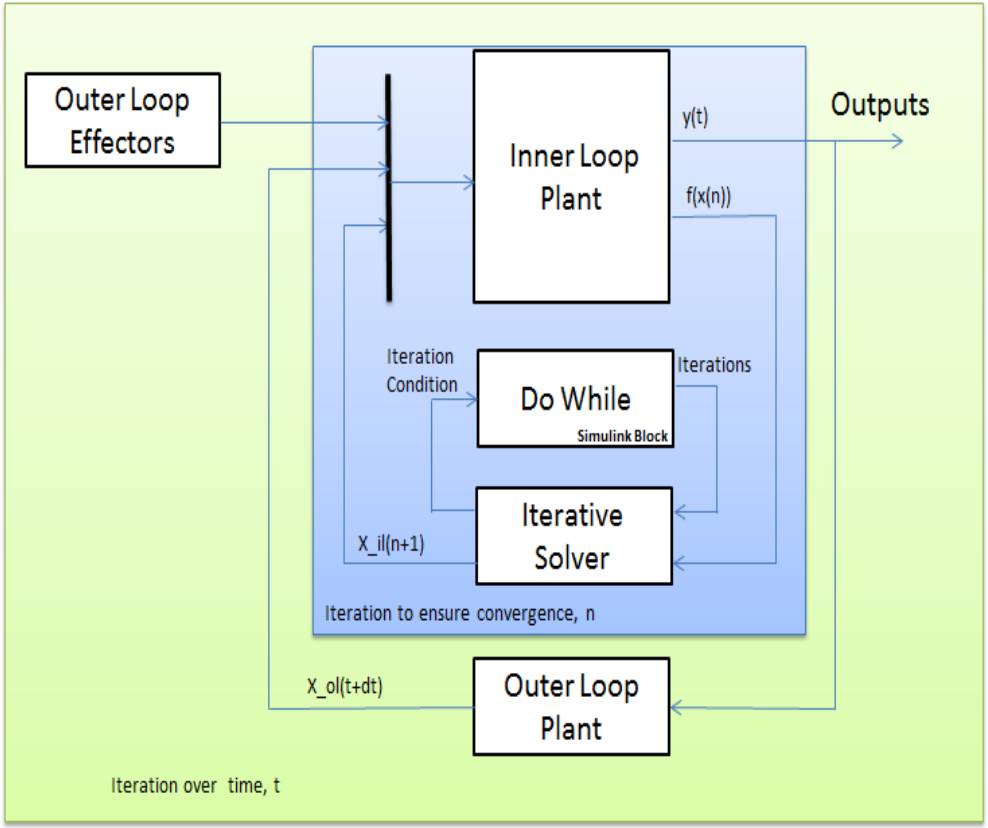
- 40,000 Lb Thrust Class High Bypass Turbofan Engine Simulation
- MATLAB/Simulink Environment
- Publicly available
- Representative dynamic performance
- Realistic controller
- Realistic surge margin calculations



2011 GRC Software of the Year Award nomination, and Exceptional Achievement Award

Toolbox for the Modeling and Analysis of Thermodynamic Systems (T-MATS)

- Simulation framework for component level model creation
- MATLAB/Simulink library structure for maximum flexibility
- Open source format
- Block sets for
  - Gas turbine components,
  - Actuators
  - Sensors
  - Basic controller systems



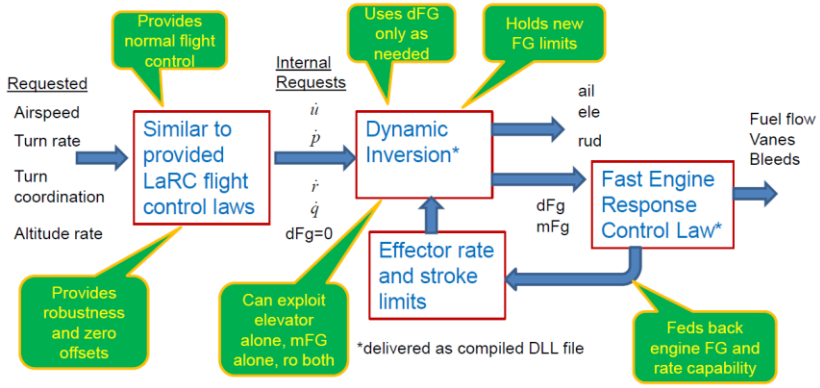
Enhanced Engine Control

- Controller Design for Enhanced Engine Response
  - Identification of engine operation risks
    - Life models
    - Stall margin models
  - Engine controller design based on enhanced performance and risk of failures
- Using Propulsion System for Loss of Control Prevention and Mitigation
  - New flight simulator update
  - Propulsion system for envelope protection
- Engine Icing Modeling, Detection and Accommodation
  - Engine icing accumulation modeling
  - Engine icing detection algorithms

Integrated Flight and Propulsion Control (IFPC)

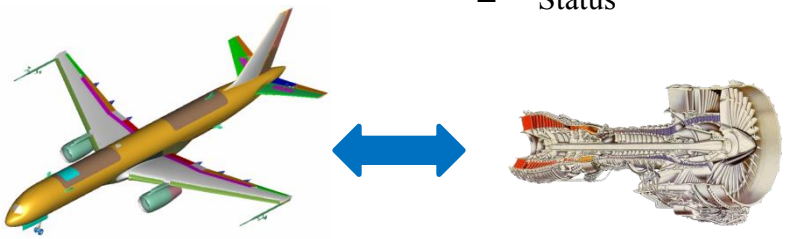
- Objective: A proof of concept IFPC package that demonstrates the abilities of integrating the propulsion system into the flight control system to prevent or mitigate the selected loss-of-control scenarios.
- IFPC Control Architecture:
  - Application of engine as novel flight effectors
  - Automatic mitigation of key system failures
  - Control strategy changes and crew interface consistent with nominal flight
  - Retain maturity of existing flight and propulsion control functions
- Results:
  - High level IFPC control architecture proposed
  - Simulation of functionalities of key modules demonstrated

High Level IFPC Control Law Architecture



To Aircraft
- Thrust feedback
- Range and rate limits
- Status

To Each Engine
- Individual thrust commands
- AOA and sideslip
- Mission segment
- Status



Thank you